CALIFORNIA
ENERGY
COMMISSION

CALIFORNIA HYDROGEN FUELING STATION GUIDELINES — EXECUTIVE SUMMARY

CONSULTANT REPORT

September 2004
600-04-002V1-ES

CALIFORNIA ENERGY COMMISSION

Prepared By:

TIAX LLC
1601 De Anza Blvd., Suite 100
Cupertino, CA 95014
Contract No. 600-01-095

Prepared For:

Sandra Fromm
Bill Blackburn
Project Managers

Susan Brown
Manager
Transportation Technology Office

Rosella Shapiro
Deputy Director
Transportation Energy Division

Robert L. Therkelsen
Executive Director

CALIFORNIA HYDROGEN FUELING STATION GUIDELINES

Executive Summary

St. Croix Research
Charles Powars

TIAX LLC
Stefan Unnasch
Erin Kassoy
Shyam Venkatesh

USA PRO & Associates
Gary Pope

SunLine Services Group
John Williams

University of California at Davis, Institute of Transportation Studies
Jonathan Weinert
Marshall Miller

Report to
California Energy Commission
1516 Ninth Street
Sacramento, California 95814-5512

Date: November 2003

Prepared by
TIAX LLC
1601 S. De Anza Blvd., Suite 100
Cupertino, California 95014-5363
Tel 408-517-1550
Fax 408-517-1553

Technical Report TR-03-163b
TIAX Case D0228

Preface

This document is the Executive Summary of a report titled "California Hydrogen Fueling Station Guidelines," which was prepared by TIAX LLC for the California Energy Commission (CEC) as part of Contract 600-01-095, "Hydrogen Fueling Infrastructure Study." The report and this Executive Summary are deliverables required under Task 3, "Development of a Hydrogen Fueling Station Report." TIAX and its subcontractors St. Croix Research, the University of California at Davis Institute of Transportation Studies, USA PRO & Associates, SunLine Services Group, ioMosaic, and SDV-SCC prepared these documents. Sandra Fromm and Bill Blackburn were the Energy Commission Project Managers.

The 120-page "California Hydrogen Fueling Station Guidelines" Task 3 report includes technical details (e.g., pertaining to the different types of hydrogen fueling stations) and individual profiles of existing hydrogen fueling stations in California. This briefer Executive Summary Task 3 report has less technical details and is bound separately.

Table of Contents

List of Tables

List of Figures

1. Introduction

This is the Executive Summary of the “California Hydrogen Fueling Station Guidelines” report, which was developed as a resource for anyone considering the installation of a hydrogen fueling station. Its objective is to provide guidance for planning, designing, siting, permitting, and procuring facilities to refuel hydrogen-fueled vehicles.

The California Hydrogen Fueling Station Guidelines report seeks to balance the needs of those who are committed to a hydrogen fueling station and need to assess equipment options, those who are considering a hydrogen fueling station and need planning guidelines, and those who are interested in general hydrogen fueling station background information. It applies to fuel cell vehicles and also hydrogen-fueled vehicles with internal combustion engines. It is intended to be applicable for a spectrum of applications ranging from refueling a small number of light-duty hydrogen vehicles to large fleets of heavy-duty hydrogen vehicles. The primary emphasis is on compressed hydrogen fueling, but liquid hydrogen fueling is also considered. Refueling fuel cell vehicles equipped with on-board reformers with methanol or other hydrocarbons is not addressed.

This Executive Summary is much briefer than the Guidelines report and it contains substantially less technical details. For example, specifics contained in the Guidelines report but not in this Executive Summary include: a listing and discussion of pertinent hydrogen properties, detailed descriptions of candidate hydrogen infrastructure and fueling station design options (the Executive Summary briefly overviews these options and provides examples), detailed discussion of the design of components such as dispensers, a review of potentially applicable codes and standards and current activities to develop codes and standards specific to hydrogen fueling stations, profiles of five hydrogen fueling stations currently operating in California, and reference citations.

In the Executive Summary, Section 2 provides an overview of the alternative hydrogen infrastructure strategies and fueling station design options, while Section 3 summarizes codes, standards, and the permitting process applicable to hydrogen fueling stations.

2. Hydrogen Infrastructure and Fueling Station Design Options

Hydrogen can either be delivered to or produced at the fueling station. It can be delivered as a trucked compressed gas, a trucked cryogenic liquid, or (in rare cases) through a hydrogen pipeline. Hydrogen can be produced at the fueling station by either electrolysis of water or reforming of hydrocarbons such as natural gas. Each of these delivery and production modes requires a significantly different fueling station design. While hydrogen dispensers are basically the same regardless of the delivery or production mode, dispensers for compressed and liquid hydrogen fueled vehicles are completely different. These combinations of hydrogen delivery or production at the station, compressed or liquid hydrogen dispensing, and various components and integration alternatives make up the array of hydrogen fueling infrastructure and station design options.

Figure 2-1 illustrates the basic hydrogen delivery or production modes and some of the fueling station design options that are appropriate to each mode. Sections 2.1 through 2.7 discuss these options. The fueling stations illustrated in Figure 2-1 are configured for compressed hydrogen dispensing. Stations that dispense liquid hydrogen are discussed in Section 2.8. Section 2.9 summarizes some guidelines for selecting a fueling station type and capacity to match a given hydrogen vehicle fleet fuel demand.

2.1 Compressed Hydrogen Delivery

Delivering compressed hydrogen to a fueling station provides a refueling option that can be implemented relatively quickly with a low capital cost. Delivered sources of compressed hydrogen include both cylinders delivered by truck and tube trailers. Figure 2-1A illustrates a hydrogen fueling station of this type:

- A truck delivers and parks a compressed hydrogen tube trailer at the station site
- The tube trailer supplies hydrogen to a compressor (the tube trailer pressure decreases as hydrogen is consumed)
- High-pressure hydrogen from the compressor is stored in pressure vessels
- The dispenser controls and meters the flow of compressed hydrogen into the vehicle fuel tank
- When the tube trailer pressure decreases to a minimum level, it is replaced with a tube trailer that has been refilled with compressed hydrogen at a central plant

A tube trailer consists of a pack of pressurized cylinders connected by a manifold and housed on a trailer. Tube trailers hold roughly 120,000 scf (280 kg) of hydrogen at pressures in the range of 2,400 to 3,100 psi. The useful mass of hydrogen stored in a tube trailer is roughly 250 kg. The entire volume of hydrogen is not available because the suction pressure of the compressor is not zero and trailers must be scheduled for swapping to prevent running out of hydrogen fuel. Typical dimensions for the trailer are 40 to 45 feet long, 10 feet high and 8 to 9 feet wide. When installed, the trailer is

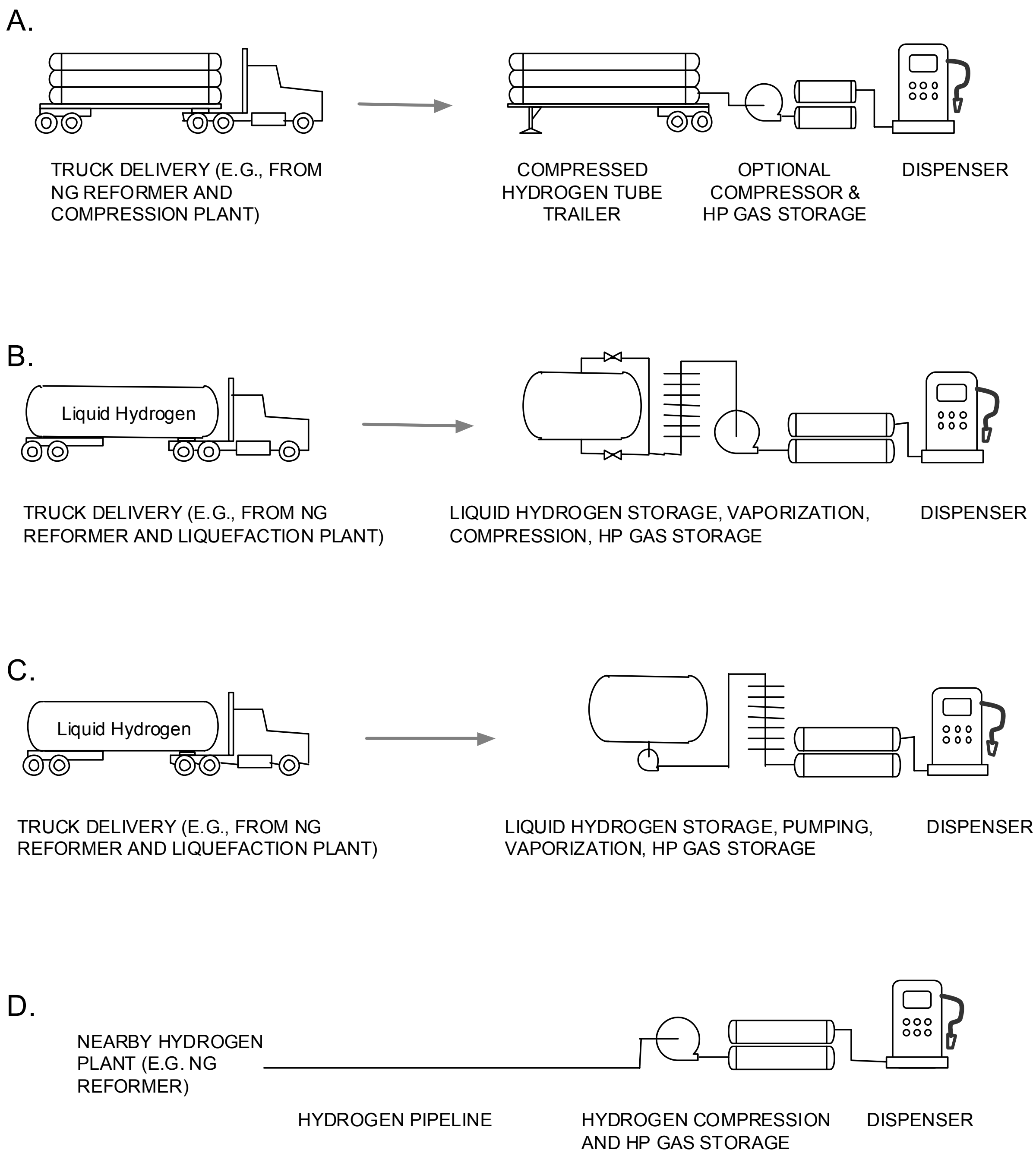
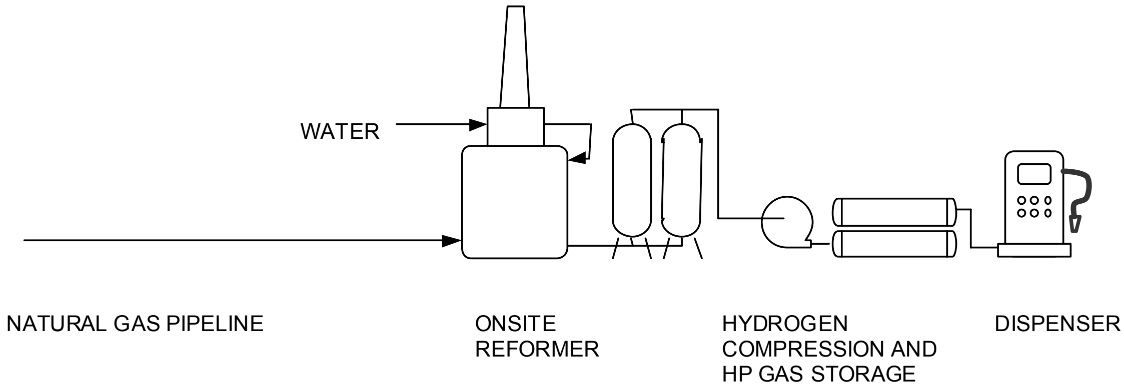
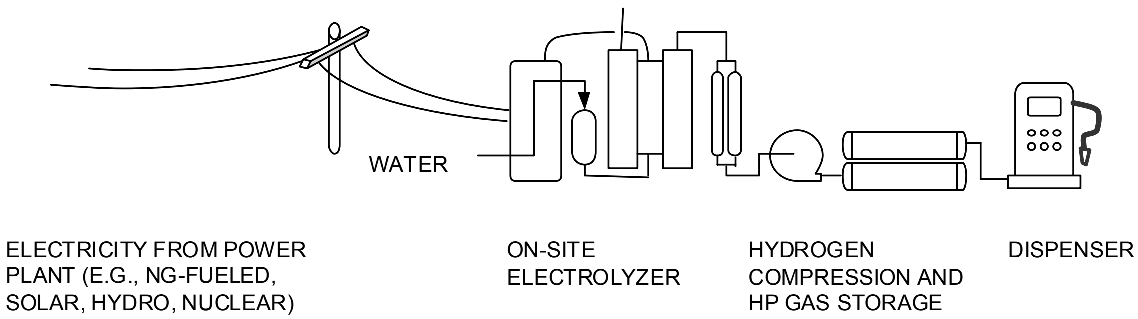


Figure 2-1. Simplified illustration of hydrogen supply and production modes including fueling station configuration options (continued on next page).

E.



F.



G.

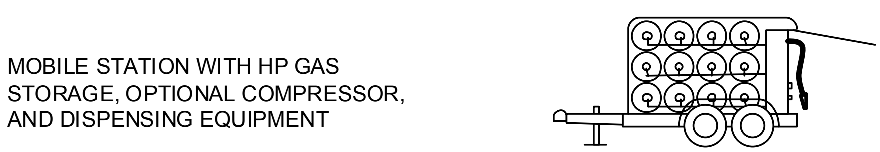


Figure 2-1. Simplified illustration of hydrogen supply and production modes including fueling station configuration options (concluded).

supported by a wheel assembly on one end and landing gear on the other. Figure 2-2 shows a hydrogen tube trailer parked at the SunLine Transit hydrogen fueling station in Thousand Palms, California.

Hydrogen can also be delivered in compressed gas cylinders. Industrial gases are typically compressed to 3,000 psi in a variety of storage vessels. The standard "K bottles" hold 300 scf of hydrogen with a water capacity of 1.8 ft^3. K bottles are often combined in a six pack, which would hold 1,800 scf or 4.3 kg of hydrogen. Industrial gas companies deliver K bottles by truck. Hydrogen delivery and storage in K bottles may be an attractive option for temporary stations or stations with an extremely low throughput. Of course, if hydrogen vehicles are to be filled completely (i.e., to their maximum pressure) or if the K bottle capacity is to be utilized efficiently, then they must be connected to a compressor similar to the arrangement previously discussed for tube trailers.

Compressed hydrogen delivery is often chosen when the fuel dispensed per day is relatively low and when the station capital cost must be minimized. This may be a good choice for relatively short demonstration projects with a low number of vehicles. Stations planned for fleets that are initially small but are expected to grow considerably

Figure 2-2. Hydrogen tube trailer and ASME pressure vessels at SunLine Transit fueling station in Thousand Palms, California.

with time can also benefit from using tube trailers. These stations could be designed for tube trailers in the early phase when the required hydrogen throughput is modest. When the number of vehicles served by the station grows and the hydrogen consumption increases, the tube trailer can be replaced by another option for hydrogen production or storage such as reformers or liquid hydrogen cryogenic tanks. The initial station design should account for the possible transition from tube trailers to other hardware.

Besides the tube trailer or k bottles, the primary components of a station utilizing compressed hydrogen delivery and storage are the compressor, pressure vessels, and dispenser. These are also components used in most of the other types of hydrogen fueling stations illustrated in Figure 2-1.

The physical properties of hydrogen, vehicle fuel purity specifications (e.g., for fuel cells), hydrogen supply, vehicle fuel storage pressure, and hydrogen flow rate are the primary factors affecting the compressor requirements. Compressor design options include the cylinder lubrication system, cooling system, motor, and piston configuration. For hydrogen compression, oil-free compressors are generally preferred over oil-lubricated designs because lubricating oil is a source of contamination for the hydrogen. Cooling between compression stages can be accomplished with air or liquid coolant. Air-cooled compressors are less complex but the cooling, cylinder life, and to some extent, power consumption, are improved with water-cooled designs.

Electric motor driven reciprocating piston compressors have been used at various hydrogen fueling stations. These compressors require multiple stages to achieve the needed storage and dispensing pressures. A piston compresses the gas at each stage and the gas is cooled before entering the next stage. The requirements of reciprocating compressors for CNG and hydrogen differ for two primary reasons. First, because of the different thermodynamic properties of hydrogen and methane (the primary component of natural gas), more stages of compression are needed to achieve a given pressure ratio for hydrogen than natural gas. Second, the required compressor discharge pressure is usually higher for hydrogen than natural gas (e.g., CNG refueling at 3,600 psi requires about 4,000 psi to storage, while hydrogen refueling at 5,000 psi requires about 6,250 psi to storage). Hydrogen and CNG reciprocating compressors may also be different due to material compatibility and fuel purity requirements. Reciprocating piston compressors may also be pneumatically or hydraulically driven and in some applications these types of compressors are referred to as intensifiers.

Diaphragm compressors are an alternative to reciprocating compressors. They are often preferred for hydrogen service because they provide a better seal than compressors and there is less chance of fuel contamination. While diaphragm compressors have maintenance and performance advantages over piston compressors, they are also considerably more expensive.

All compressed hydrogen fueling stations have some form of high-pressure gas storage between the compressor and dispenser. Buffer storage refers to one or more vessels that are at the same pressure. The purpose of this type of storage is to dampen (or buffer) short-term variations between the dispenser and compressor flow rates. Buffer storage is well suited for relatively constant fuel dispensing demands. In cascade storage, some number of vessels or banks of vessels (usually three) are used to refuel the vehicle(s) in a “cascaded” fashion. When refueling begins and the vehicle tank pressure is low, gas is drawn from the lowest pressure vessel. As the vehicle fills and its tank pressure increases, gas is drawn from higher pressure vessels. The vessels are also refilled by the compressor in a cascade fashion. This strategy makes more efficient use of a given volume of storage capacity in multiple vessels, and it is well suited for stations with highly peaked dispensing-demand periods.

The buffer or cascade storage vessels are typically steel cylinders that are designed, fabricated, tested, and marked as specified by the American Society of Mechanical Engineers (ASME) boiler and pressure vessel code. California law requires ASME certification for essentially all high-pressure vessels installed in stationary facilities (California Code of Regulations Title 8). The large cylinders installed on the ground near the tube trailer in Figure 2-2 are ASME pressure vessels.

The design of compressed hydrogen dispensers has generally evolved from many years of experience with CNG dispensers. Many companies that manufacture CNG dispensers also market compressed hydrogen dispensers. Figure 2-3 shows an example compressed hydrogen dispenser. The principal components of a compressed hydrogen dispenser are:

- The dispenser cabinet or housing
- User controls (or interface) and information display
- Fill nozzle(s)
- Hose(s)
- Break-away connector(s)
- Flow meter and other transducers
- Control system
- Filter
- Tubing, valves, and various fittings
- Safety systems

Depending on the application and manufacturer, optional dispenser components may include:

- A card lock system or other access-control and payment device
- Priority-sequence control for cascaded gas storage vessels
- A second hose and nozzle (typically to dispense hydrogen to a different fill pressure)
- Heat-of-compression compensation algorithm
- Vehicle data interface and controls

Hydrogen dispensers can have a variety of outward appearances and housing designs. CNG experience has shown that the general public prefers that all automotive fueling dispensers resemble gasoline dispensers (e.g., Figure 2-3); however, this is not a factor for heavy-duty fleet vehicle refueling. The fill nozzle connects to the mating

Photograph courtesy Fueling Technologies Inc.

Figure 2-3. Typical compressed hydrogen fueling dispenser with two hoses providing 3,600 psi and 5,000 psi vehicle refueling capability.

receptacle on the vehicle. Following CNG safety practice, a 5,000-psi nozzle can be connected only to a 5,000-psi receptacle, but a 3,600-psi nozzle can be connected to either a 3,600 or 5,000-psi receptacle.

An important part of the controls and software built into hydrogen dispensers are the systems that compensate for ambient-temperature and heat-of-compression effects. Ambient-temperature compensation is needed, for example, if a hydrogen vehicle is slow-filled to 5,000 psi on a cold morning and is left undriven in the sun so that the fuel tank pressure rises above 5,000 psi. To prevent this from occurring, safety codes require that dispensers fill tanks to no more than the “temperature-corrected” fill pressure, which takes into account the possibility that the tank temperature may increase if the ambient temperature is low.

Heat-of-compression effects occur only during fast-filling. Basically, the work done on the gas as it is being compressed in the vehicle fuel tank increases its internal energy, temperature, and pressure. After refueling, heat transfer causes the fuel tank temperature and pressure to decrease. Therefore, a tank that is fast-filled to 5,000 psi, for example, will "settle" to a pressure significantly less than 5,000 psi, and so a full fill was not achieved. To compensate this, the tank must be filled to an initial pressure greater than 5,000 psi, although there are various limitations on the maximum initial fill pressure. The CNG industry has advanced dispenser control algorithms and fill procedures for heat-of-compression compensation; however, because of the gas property differences and the higher pressures involved, heat-of-compression compensation is more challenging for hydrogen than natural gas. For this reason, the California Fuel Cell Partnership (CaFCP) is developing a compressed hydrogen refueling protocol that includes data transmission from the vehicle fuel tank to the dispenser to more accurately compute the needed heat-of-compression compensation factor. This system, which includes a data-transmission cable that is connected to the vehicle during refueling, is being evaluated as an alternative to systems that estimate the heat-of-compression compensation factor without data transmission.

2.2 Liquid Hydrogen Delivery

Liquid hydrogen is the other alternative for transporting and storing hydrogen at a fueling station. When hydrogen at atmospheric pressure is cooled to -423°F and its heat-of-vaporization is removed, it condenses to a liquid. Figure 2-1B and C illustrate the two liquid hydrogen delivery infrastructure and fueling station design concepts.

The primary advantage of liquid hydrogen transportation and storage is its relatively high density. Figure 2-4 compares the density of liquid hydrogen (saturated at pressures from 1 atmosphere to the critical pressure) to the density of compressed hydrogen (from 3,600 psi to 5,000 psi). Density is shown in the hybrid units of kg/gallon because one kg of hydrogen has approximately the same lower heating value (LHV) as one gallon of gasoline, and so hydrogen would have to be stored at 1 kg/gal to have the same energy density as gasoline. As shown in Figure 2-4, the density of liquid hydrogen is approximately three to four times the density of compressed hydrogen gas. Liquid hydrogen is delivered in cryogenic tank trucks, which typically have a capacity of 10,000 to 15,000 gallons. Therefore, they hold almost ten times more hydrogen mass than a tube trailer.

The main disadvantages of liquid hydrogen are associated with its very low temperature. Special cryogenic equipment is required to produce, store, and process liquid hydrogen. Even with this special cryogenic equipment, some boil-off loss inevitably occurs at various points in the infrastructure chain. This boil-off loss can be negligible for fueling stations with a high throughput, but it can be substantial for low-throughput stations.

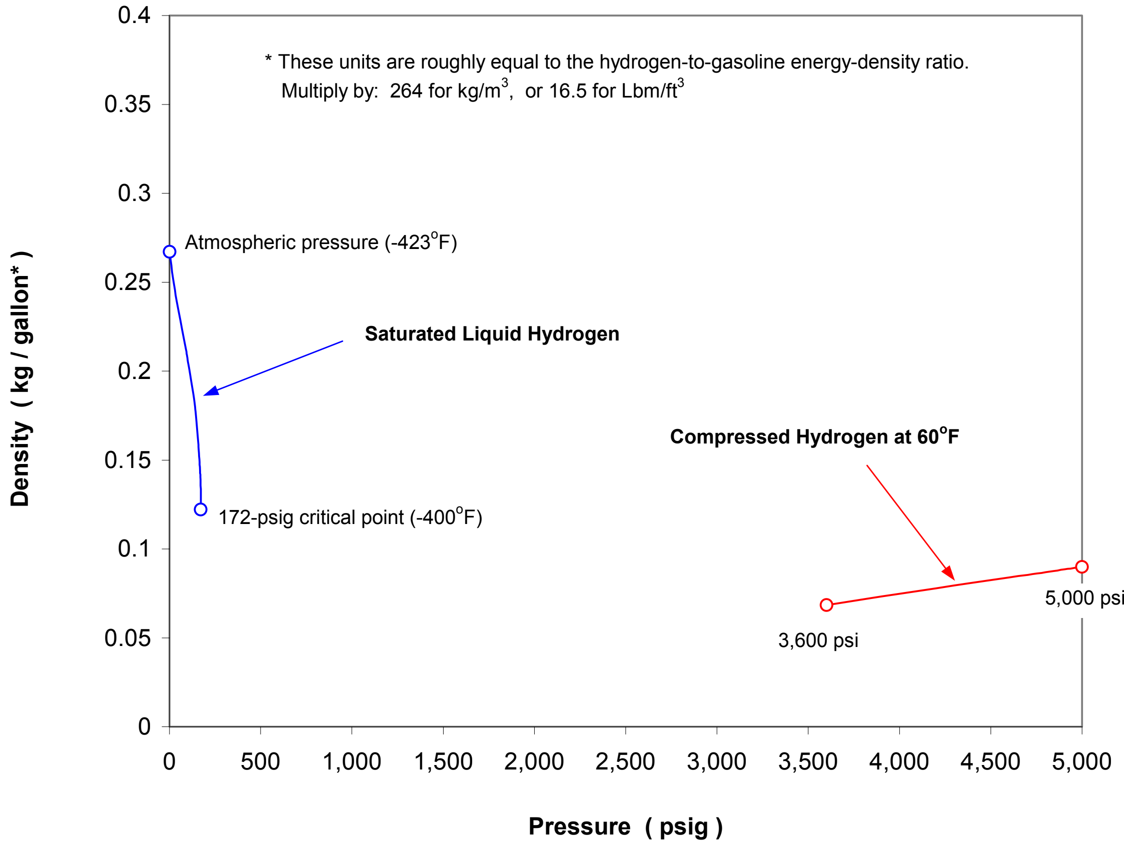


Figure 2-4. Mass density of compressed and liquid hydrogen at conditions applicable to hydrogen vehicles and fueling stations

There are two optional designs for stations that receive and store liquid hydrogen and dispense compressed hydrogen:

- Stations that vaporize liquid hydrogen from the storage tank, compress the vapor to a high pressure, store the high-pressure gas in buffer or cascaded vessels, and dispense the compressed hydrogen (Figure 2-1B)

- Stations that pump the liquid hydrogen to a high pressure, vaporize[1] and warm this high-pressure gas, store it in buffer or cascaded vessels, and dispense the compressed hydrogen (Figure 2-1C)

Stations of the first type are conceptually similar to stations with tube trailers, electrolyzers, or reformers, except the liquid hydrogen storage tank replaces the tube trailer, electrolyzer, or reformer. Stations of the second type take advantage of the fact that much less power is required to pump a liquid (or cold supercritical fluid) to a given

[1] Hydrogen is a supercritical fluid above its critical pressure of 187 psia. Therefore, the terms “vaporize” and “vaporizer” are not technically correct in this regime, but they are used here because that usage is common practice.

pressure than to compress an ambient-temperature gas to the same pressure. The power savings is more than a factor of ten for 60 psig liquid hydrogen pumped or vaporized and compressed to 6,250 psig.

Figure 2-5 is a schematic sketch that shows the components of the second type of station in more detail. A key component is the cryogenic pump, which is significantly different than a conventional liquid pump. The liquid hydrogen is stored in the tank in a saturated state, which means that the liquid and vapor phases are in equilibrium (i.e., the liquid is boiling at a low rate, as in a quietly whistling tea kettle). A boiling fluid is challenging to pump. For example, a considerable quantity of liquid is vaporized in order to cool down and prime a pump that has been idle.

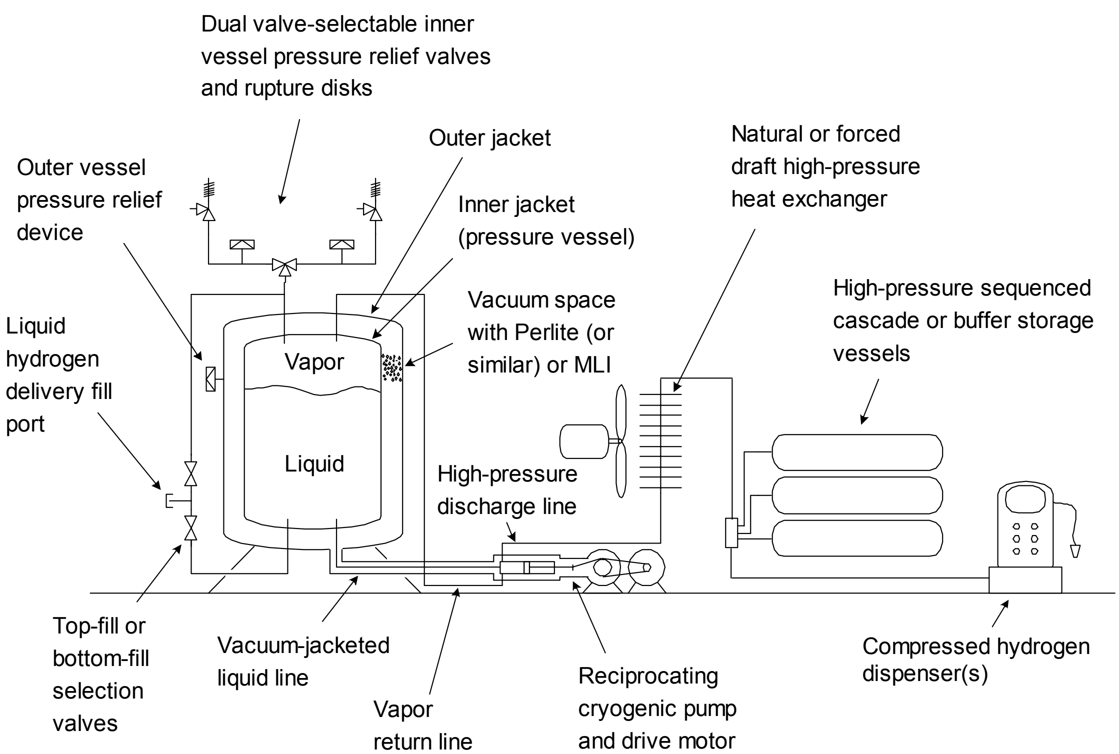


Figure 2-5. Schematic illustration of a hydrogen fueling station that receives and stores liquid hydrogen, pumps and warms the hydrogen, and stores and dispenses compressed hydrogen gas

The tradeoffs associated with these two liquid hydrogen storage station designs are such that the design utilizing a compressor (Figure 2-1B) is best suited for stations with low vehicle throughput and hydrogen consumption, and the design utilizing a pump (Figures 2-1C and 2-5) is better for stations with high vehicle throughput and hydrogen consumption. The high vehicle throughput ensures that the pump will not be subject to frequent warm-up/cool-down cycles, and the high hydrogen throughput ensures that the amount of hydrogen vaporized and vented will be a small percentage of the total dispersed. In this situation, a liquid hydrogen station with a pump provides significant advantages, including the lower initial cost of a pump relative to a compressor and substantially lower operating costs for power and maintenance.

This same basic design approach has been used for stations that dispense CNG from stored LNG that is pumped and vaporized (these are commonly referred to as L/CNG stations). For example, Ominitrans (the transit agency serving the San Bernardino area) operates two L/CNG stations that routinely dispense about 10,000 gallons of LNG (vaporized to CNG) into 100 CNG buses every evening.

In spite of its efficiency disadvantages, stations that utilize a vaporizer and compressor (Figure 2-1B) are better suited for stations that sporatically refuel a small number of vehicles. This is because no liquid hydrogen is vaporized and vented in order to prime the pump, and some of the hydrogen that might otherwise be vented can be compressed into the buffer or cascade storage tanks (depending on the specific station design). The CaFCP station in West Sacramento utilizes this design. Figure 2-6 is a photograph of this station, which shows the LNG storage tank (the elevated white cylinder), the vaporizer (the long verticle objects toward the left) and the two compressed hydrogen dispensers (one for 3,600 psi and one for 5,000 psi). This station also has the capability to dispense liquid hydrogen using a Linde nozzle system, which is discussed in Section 2.6.

A key component of this type of fueling station is the liquid hydrogen storage tank. Figure 2-5 illustrates the basic construction of these cryogenic vessels. They are double-wall construction with a vacuum space in between to insulate the cold liquid hydrogen from heat transfer from the much warmer environment. The rate at which the hydrogen boils depends on this heat transfer. This boiling increases the tank pressure,

Figure 2-6. The CaFCP hydrogen fueling station in West Sacramento is an example of a station that receives and stores liquid hydrogen and dispenses compressed and liquid hydrogen.

or it must be constantly vented, so it is prudent to reduce the heat transfer to an absolute minimum. The inner tank is typically stainless steel designed and tested consistent with the ASME pressure vessel code. The outer tank or “jacket” is typically carbon steel. The vacuum space is filled with a low-conductivity granular material such as Perlite or multi-layer insulation (MLI) to minimize both radiation and convection heat transfer. The inner tank has various pressure-relief devices (Figure 2-5) consistent with applicable codes. Two important specifications (in addition to capacity) affecting liquid hydrogen tanks are the maximum allowable working pressure (MAWP) and normal evaporation rate (NER). Cryogenic tanks of this type are available as shop-fabricated products in sizes up to approximately 50,000 gallons.

2.3 Hydrogen Pipeline Delivery

In principle, hydrogen can be delivered to the station through a hydrogen pipeline, and compressed, stored, and dispensed as sketched in Figure 2-1D. There are, however, very few hydrogen pipeline networks in the United States, and the only ones in California are local to a few petroleum refineries and industrial process plants. Therefore, except in a very few locations, this type of station is not an option at this time and is not addressed in detail in this document.

2.4 On-Site Reforming

Technologies that produce hydrogen from natural gas or other hydrocarbon feedstocks are typically called reformers because they *reform* the hydrocarbons into carbon monoxide (CO) and hydrogen. A reformer can be installed on-site at a hydrogen fueling station, in which case no liquid or compressed hydrogen deliveries are required (Figure 2-1E).

Figure 2-7 is a simplified schematic of an example configuration for a hydrogen fueling station with an on-site reformer. The principal elements of the hydrogen production system are the natural gas and air supply, reformer, and purification system. The configuration details differ with each reforming option.

In general, hydrogen and other gases are produced in the reformer, a pressure swing adsorption system is used to purify the hydrogen product stream, and the purified hydrogen is compressed, stored in buffer or cascaded vessels, and dispersed to vehicles as discussed in previous sections. Several reformer technologies are already used commercially for hydrogen production (mostly for non-vehicle applications) and have a near to long term potential for being available for refueling station on-site hydrogen production. A challenge in using reformers for on-site hydrogen production is that most of these approaches have not been available as integrated systems at a scale appropriate for projected near-term hydrogen vehicle fueling requirements (approximately 20 to 1,000 kg/day). In addition, reformers are best operated under steady-state conditions and therefore require a relatively constant demand for hydrogen; however, on-site reforming does offer the promise of relatively low cost hydrogen compared to other decentralized production methods.

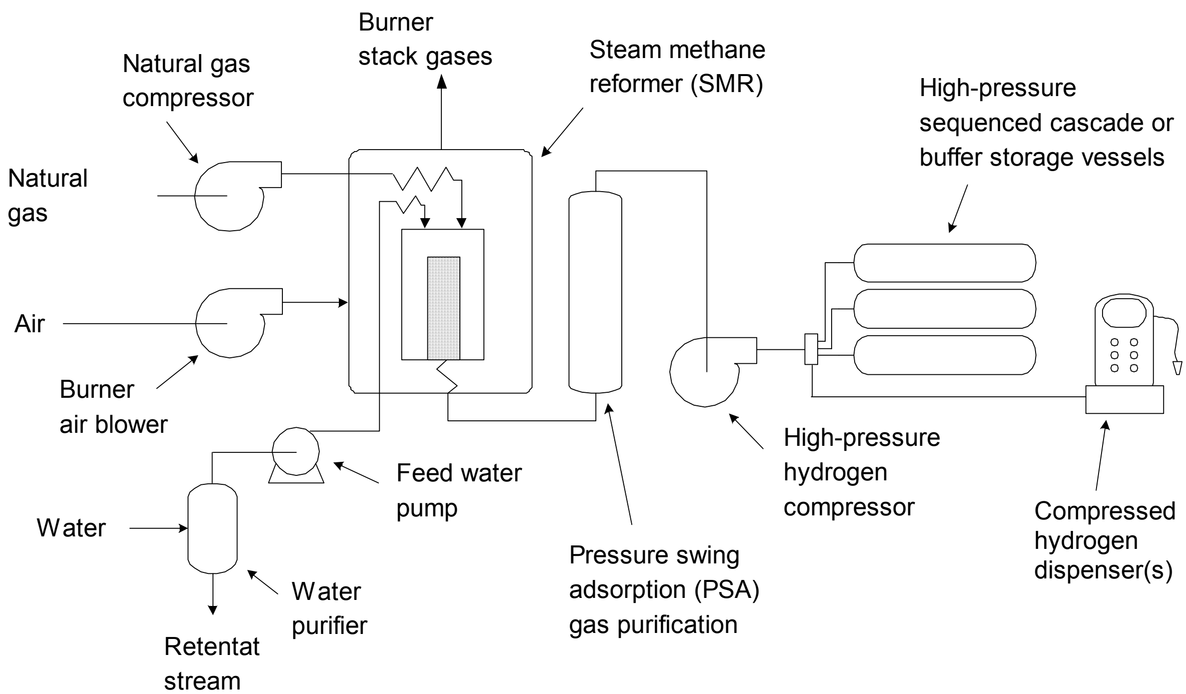


Figure 2-7. Simplified process flow schematic for a hydrogen fueling station with an on-site reformer

Three basic reformer technologies are potentially applicable to hydrogen production on-site at refueling stations: steam reforming (SR), partial oxidation (POX), and autothermal reforming (ATR). Table 2-1 summarizes these technologies and their primary tradeoffs. The following discussions focus on hydrogen production by methane reforming, but methanol and other hydrocarbons can also be reformed to produce hydrogen.

In a steam reformer, hydrogen production is accomplished in several steps: a steam reforming step followed by a water gas shift reaction and hydrogen purification. This is the most well known, commercially available process for hydrogen production. In the United States, nearly 90 percent of the hydrogen is manufactured through the steam reformation of natural gas.

Steam reforming involves the reaction of natural gas (or other hydrocarbon feedstocks) with steam to produce CO and hydrogen. The steam reforming reaction requires external heat input, which is often provided by the combustion of waste gases. Further processing of the gas stream with steam in a shift reactor produces CO_2 and additional hydrogen. The gas exiting the shift reactor contains mostly H_2 (70 to 80 percent) plus CO_2, CH_4, H_2O and small quantities of CO. Hydrogen is then purified, typically by pressure swing adsorption (PSA) systems. The product hydrogen can have a purity of up to 99.999 percent. A purity of 98 percent hydrogen is specified in ISO 14687 for fuel cells for transportation and stationary applications. Compared with other reforming approaches, a high temperature steam reformer with methane feedgas can be expected to produce the greatest amount of hydrogen per unit of natural gas.

Table 2-1. Summary of hydrocarbon reforming processes.

Method	Principle	Considerations
Steam Reforming (SR)	Reform methane using steam. $CH_4 + H_2O \rightarrow CO + 3H_2$ (Also applicable to methanol reforming)	Advantage: High purity product to ~75% (no nitrogen dilution). High efficiency. Disadvantage: Requires steam for initial operation making startup more complex. Requires sophisticated equipment design and high-grade metallurgies.
Partial Oxidation (POX)	Oxidation of CH4 $CH_4 + ½\, O_2 \rightarrow CO + 2H_2$	Advantage: Quicker start-up. No requirement for steam to POX reaction. Suitable for heavier hydrocarbons Disadvantage: Maximum of 2 hydrogen moles produced per mole of methane feed. Low purity product (~35%) making purification more difficult. Low efficiency.
Autothermal Reforming (ATR)	Combination of partial oxidation and steam reforming. $CH_4 + ½\, O_2 \rightarrow CO + 2H_2$ $CH_4 + H_2O \rightarrow CO + 3H_2$	Advantage: Quicker start-up. Efficiently uses heat produced by partial combustion for endothermic steam reforming. Reformate product hydrogen can be as high as 55%. Material is near shift equilibrium at exit of reforming bed. No fired heater or higher grade metallurgies required.

Partial oxidation reformers use oxygen (as either oxygen in air or pure oxygen) to partially combust hydrocarbon fuels to carbon monoxide and hydrogen. Methane (or some other hydrocarbon feedstock) is oxidized to produce carbon monoxide and hydrogen. The hydrogen content of the product reformate from partial oxidation systems is typically 30 to 33 percent (dry). The balance is carbon dioxide and nitrogen, making purification by pressure swing absorption, with reasonable recovery, difficult.

Catalysts are not required because of the high temperature; however, the hydrogen yield per mole of methane input (and the system efficiency) can be significantly enhanced by use of catalysts. A hydrogen plant based on partial oxidation includes a partial oxidation reactor, followed by a shift reactor and hydrogen purification equipment. Large-scale partial oxidation systems have been used commercially to produce hydrogen from hydrocarbons such as residual oil, for applications such as refineries. Large systems generally incorporate an oxygen plant, since operation with pure oxygen rather than air reduces the size and cost of the reactors.

Autothermal reformers employ a partial oxidation step followed directly by steam reforming, generally in the same vessel. The steam required for the steam reforming step can be passed through the partial oxidation bed to decrease the peak temperature experienced. Table 2-1 shows the chemical reactions. When using atmospheric air, every mole of O_2 results in 3.76 moles N_2 in ATR product, which must be subsequently removed from the product stream.

This system makes use of the heat produced in the exothermic oxidation reaction by passing it directly to the steam reforming bed. This means that no fired heater or expensive metallurgy is required to transfer that heat to the process stream for reforming. Relative to the partial oxidation process, less air is required because not all the methane conversion takes place in the partial oxidation section of the plant. Unconverted methane passing from the partial oxidation zone is further converted in the steam reforming section of the process. The cost of the process equipment is less than steam reforming because peak temperatures in this process do not require special metallurgy.

The reformate product hydrogen purity from an ATR process can be as high as the 50 to 55 percent. The improvement over POX is due to the more efficient conversion of methane in the steam reforming bed. An advantage of the system is that the heat used to promote the reforming reaction is produced in-situ. This simplifies the equipment design required to provide sufficient heat to the reforming bed. With higher product purity than POX, the PSA purification step can be more efficient, providing hydrogen recovery in the range of 70 percent.

The requirements for a hydrogen fueling station with a reformer depend on factors such as equipment count and size, utility hookups, and code requirements. Figure 2-7 illustrated the principal elements of such a station with a steam reformer and PSA purifier. Several subsystems make up the reformer. These include the reformer itself, heat exchangers for preheating and steam supply, shift reactors, and the purification system, natural gas, air, and water supplies.

Packaging and integration varies greatly among reforming systems. Most current generation systems are containerized for easy shipping and quick installation. Field assembly is or will be limited to providing utilities and anchoring the reformer container at the customer's facility. Examples of reformer systems include the Air Products steam methane reformer recently installed at the City of Las Vegas and the unit being developed by Hyradix for SunLine Transit.

Similar compact designs include a steam reformer system under development by H2Gen (Figure 2-8). This system is intended to require only natural gas, electric and water hookups, with pure hydrogen exiting the system. Low-pressure hydrogen would be produced, which would require compression, storage, and a dispenser for vehicle fueling.

Several studies have projected efficiencies and energy requirements for steam reformers that might be used on-site at a hydrogen fueling station. Near-term efficiencies (based on the lower heating value of the hydrogen product relative to the lower heating value of the feedstock) are likely to be 65 to 70 percent.

Figure 2-8. H2Gen steam reformer system. Hydrogen production capacity is about 25 kg/day.

2.5 On-Site Electrolysis

In principle, an electrolyzer is basically a fuel cell operating in reverse — electricity is consumed to produce hydrogen and oxygen from water. Electrolysis has been used for many years to produce hydrogen for various industrial applications, but the total production by electrolysis is much less than the production by natural gas reforming. A key parameter for electrolyzers is the ratio of hydrogen production to electric power consumption.

Electrolyzers are available in a range of hydrogen production capacities including those appropriate to on-site application at a hydrogen fueling station (as illustrated in Figure 2-1F). Figure 2-9 is a simplified schematic showing the principal components of a hydrogen fueling station with an on-site electrolyzer. Electrolyzers have received considerable attention because they use only water and electricity as inputs, and therefore they can produce hydrogen without fossil fuels and with zero emissions. If the electric power is produced by solar, hydro, or other non-fossil means, electrolyzers may eventually be an element of an all-renewable-energy hydrogen fuel strategy.

An advantage of a station with an electrolyzer is that deliveries of compressed or liquid hydrogen are not required, and on-site storage of large quantities of fuel is also unnecessary; however, electrolyzer economics favor near-continuous operation, and therefore stations with electrolyzers are best suited for time-fill applications, although regularly timed fast-fill refueling is possible with moderate buffer or cascade storage capacity.

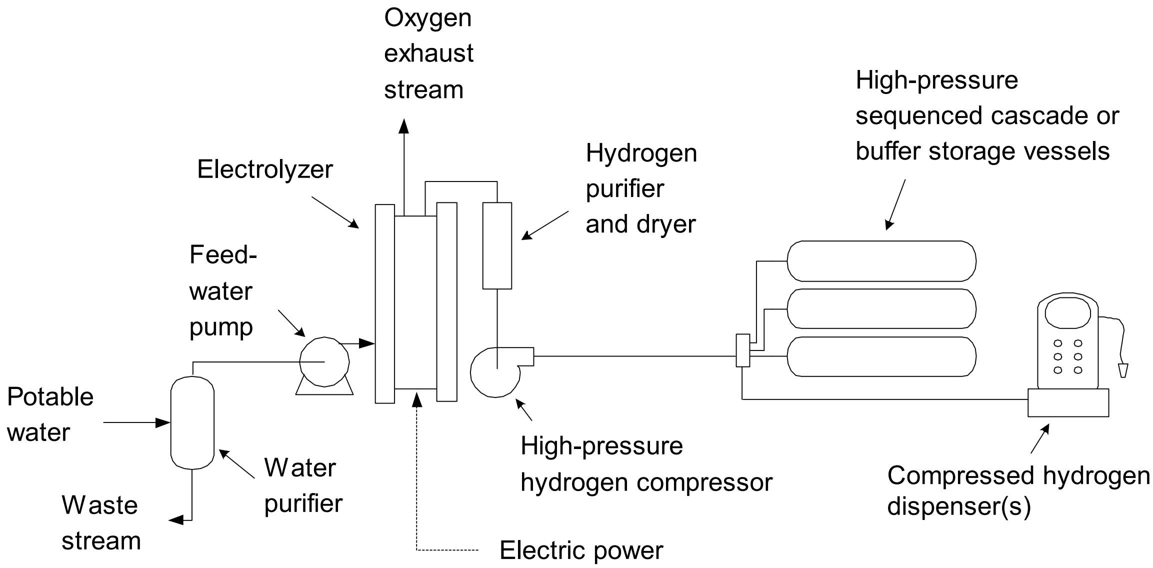


Figure 2-9. Simplified process flow schematic for a hydrogen fueling station with an on-site electrolyzer

For hydrogen fueling station application, the electrolyzer efficiency is often defined as the lower heating value of the hydrogen output divided by the input electrical energy. A thermochemical energy balance indicates that a 100 percent efficient electrolyzer requires approximately 33 kW-hr per kg of hydrogen production. Real electrolyzer efficiencies can range from approximately 60 to 90 percent, depending on various design and operating details; however, it is clear that the overall efficiency of producing hydrogen using a reformer is superior to using the hydrocarbon feedgas to generate electricity to power an electrolyzer. This is why nearly all large-scale hydrogen production in the U.S. is by reforming, and large-scale production by electrolysis is used primarily in areas with low-cost electricity (e.g., due to hydro generating resources).

At existing hydrogen fueling stations with on-site electrolyzers, most of the electricity to power the electrolyzer is usually obtained from the utility grid, and this electricity is typically produced in power plants using fossil fuels. It may also be produced from renewable resources, as previously discussed. Some initial hydrogen fueling stations installations with on-site electrolyzers also include solar energy systems, which supply part of the electric power for the electrolyzer. For example, Figure 2-10 shows the hydrogen fueling station at American Honda in Torrance, California. The small-capacity electrolyzer is in one of the modules under the canopy, and the solar photovoltaic panels (which supply part of the electrolyzer power) are

Figure 2-10. Honda's hydrogen fueling station in Torrance, California, is an example of a station with an on-site electrolyzer, which is partially powered by a solar photovoltaic system.

visible in the background. The SunLine Transit hydrogen fueling station in Thousand Palms, California, also includes an electrolyzer, which is partially powered by a solar photovoltaic system.

Alkaline and solid polymer electrolyte (SPE) membrane electrolyzers are the two most common types used for hydrogen production. These two technology options differ in their cost (operating and capital), reliability, and efficiency. Alkaline is the oldest electrolysis technology, and the one most typically used for large-scale electrolytic hydrogen production. Diluted potassium hydroxide (KOH) or sodium hydroxide (NaOH) are normally used as the electrolytes. Alkaline electrolyzers typically have electrical efficiencies of 60 to 80 percent. High-temperature alkaline electrolyzers have electrical efficiencies as high as 90 percent, but these designs present more durability-affecting materials challenges.

The principal components of an alkaline electrolyzer system for hydrogen production are:

- Cells and electrodes — Alkaline electrolyzers require the use of gas separators between the electrodes to prevent the migration of hydrogen to the oxygen side and vice versa. The electrodes are typically porous with nickel-based catalysts.

- Water purification — Demineralizers, reverse-osmosis units, and/or carbon filter cartridges produce the high-purity water required by electrolyzers.

- Gas generation system, seals, and electrolyte handling — These components include: conductivity sensor, leak detector, feed water bowl level sensor, feed pumps, cell stack temperature and water level control, ventilation blower, water seals, demisters, hydrogen ballast and hydrogen gas analyzer, and a deoxydizer.

- Hydrogen purification and dryer system — A twin-bed regenerative molecular sieve dryer, coalescing filters, and carbon adsorbtion filters are typical components used to dry and purify hydrogen intended to be used as a fuel cell vehicle fuel.

Additional components are required to compress, store, and dispense the hydrogen when the alkaline electrolyzer is part of a hydrogen fueling station. These components are identical to the ones previously discussed for other types of hydrogen fueling stations.

Solid polymer electrolyte (SPE) membrane electrolyzers operate as reverse proton exchange membrane (PEM) fuel cells, and they typically use similar parts and materials. In SPE electrolyzers, a solid-state ion-conducting membrane (the SPE) replaces the liquid electrolyte used in alkaline electrolyzers.

PEMs are solid fluoropolymers, which have been chemically altered to make them electrically conductive. The polymers are typically perfluorocarbon sulfonates. One common type is polyfluorotetraethylene (PFTE), commonly referred to as Nafion®, which is the membrane material used in some PEM fuel cells. Because of the low internal resistance of SPE membrane assemblies, they can operate at higher efficiencies than alkaline electrolyzers. SPE efficiencies of 90 percent have been reported. While SPE electrolyzers have the potential for high efficiency, the actual efficiency depends on the load factor. Higher loads result in more power consumption, but they also increase the hydrogen output. Similar load versus efficiency tradeoffs are exhibited with PEM fuel cells, batteries, and other electrochemical devices.

SPE electrolyzers require components similar to alkaline electrolyzers for hydrogen processing prior to compression, storage, and dispensing for fueling station applications.

Various companies currently manufacture electrolyzers that are suitable for hydrogen fueling stations. Some of these electrolyzers are integrated into modules that include the compressor and equipment for water pretreatment and hydrogen purification, as well as the electrolyzer itself. Figure 2-11 shows such a module manufactured by Stuart Energy Systems, which is installed at the California Fuel Cell Partnership satellite station in Richmond, California.

Figure 2-11. The Stuart Energy electrolyzer at the California Fuel Cell Partnership satellite hydrogen fueling station in Richmond, California, is an integrated unit that includes the electrolyzer, compressor, and auxiliary equipment.

2.6 Mobile Hydrogen Fueling Units

Fueling facilities in general and hydrogen fueling facilities in particular can be permanent installations, skid-mounted, portable, mobile, or wet-hosing units. These terms do not always have precise and universally agreed-on definitions. However, the implications of a permanent fueling station are reasonably clear, and a mobile fueling station is defined here as a wheeled unit (either towed or driven) that is fully self-contained. It does not “hook up” to a compressor or dispenser; it has its own dispenser and perhaps compressor, and it remains on wheels while it is being used. Wet-hosing refers to a mobile fueling unit that travels to the equipment being refueled instead of the equipment traveling to the parked refueling unit.

Figure 2-1G showed one example concept for a mobile hydrogen unit. This trailer (or it could be a truck) consists of some number of compressed hydrogen vessels, control and metering equipment, a dispenser with a hose and nozzle, and appropriate safety systems. The compressed hydrogen vessels would most logically be arranged as a priority-sequenced cascade in order to increase the storage efficiency (i.e., to maximize the number of vehicles that could be refueled before this type of mobile fueling unit had to be refilled). Figure 2-12 is an artist’s rendering of the Air Products and Chemicals Mobile Hydrogen Fueling Unit, which is a mobile fueling station of this type. This unit holds 162 kg of hydrogen (up to 120 kg usable), and features a priority-sequenced pressure vessel cascade, 3,600 or 5,000-psi refueling, and monitoring telemetry.

Graphic courtesy APCI

Figure 2-12. Air Products and Chemicals Mobile Hydrogen Fueling Unit

Higher storage efficiencies can be obtained if the mobile fueling unit includes a compressor. Quantum Technologies has announced that they have developed a mobile hydrogen fueling station (which they designate as the HyHauler™) that includes a high-pressure storage vessel cascade and an on-board compressor.

A different type of mobile hydrogen fueling unit concept produces hydrogen using an on-board electrolyzer or reformer. Such units require connection to water or natural gas (and electric) supplies, and they must also include compression, storage, and dispensing equipment. Mobile hydrogen fueling units with small electorlyzers have been built and demonstrated, but no mobile units with reformers are known.

The Stuart Personal Fueling Appliance™ Is an example of this type of mobile hydrogen fueling station. It is a relatively small unit with an electrolyzer and compressor that is reported to operate from a 240-volt electric supply and a "garden hose" water source. Stuart also offers their Community Fueler, which is an electrolyzer-based hydrogen fueling station installed in a trailer to provide a larger-capacity mobile unit. This system includes Stuart's 3 kg/hr Model CF 1350 electrolyzer together with a compressor, cascade storage vessels, dispenser, and safety systems. Figure 2-13 shows a trailer-installed Stuart Community Fueler that has been delivered to the City of Chula Vista to support their hydrogen bus and automobile project.

Photograph courtesy Stuart Energy

Figure 2-13. Stuart trailer-installed elecrolyzer "Community Fueler" delivered to Chula Vista.

Mobile hydrogen fueling units may be well suited for hydrogen vehicle fleets with very low kg/day consumption or with growth projections too uncertain to support permanent station planning. They can also be used to provide temporary fueling while a permanent station is being installed. The most common application of mobile hydrogen fueling units to date has been to support fuel cell vehicle exhibitions and demonstrations at locations with no hydrogen fueling stations. While mobile hydrogen fueling units are well suited to many situations, permanent stations have lower lifecycle costs for established fleets with substantial kg/day hydrogen consumption. Planners should be alert to issues associated with permitting and/or code-compliant use of mobile hydrogen fuelers, particularly in California, because there is substantial uncertainty associated with codes and standards applicable to mobile hydrogen fueling units that are "parked" at a site and used to refuel vehicles. Planners should check with state and local authorities regarding the latest status of regulations affecting mobile hydrogen fueling unit applications.

2.7 Stations that Dispense Liquid Hydrogen

There are very few hydrogen fueling stations in the U.S. that dispense liquid hydrogen, and two of these are in California: the CaFCP station in West Sacramento and the BMW station in Oxnard. These stations utilize liquid hydrogen dispensing technology that was developed by various organizations in Germany (in the 1970s and 1980s, primarily for refueling hydrogen vehicles with internal combustion engines), and the Linde Company has continued this development through the present time.

There are several challenges associated with the dispensing of liquid hydrogen into motor vehicles:

- Boil off — As refueling is initiated, the flowing liquid hydrogen cools down certain station and vehicle fuel system plumbing from ambient to cryogenic temperatures. This vaporizes some of the liquid hydrogen, and the quantity of vapor generated is relatively high because of hydrogen's low heat-of-vaporization.

- Contamination and Condensation — All plumbing involved in the refueling process that was exposed to the ambient environment must be thoroughly purged of air and moisture (that would freeze) before the refueling process starts.

- Safety — Current liquid hydrogen dispensing systems incorporate various special safety features such as an automatic leak check prior to enabling the flow of liquid hydrogen.

Figure 2-14 shows the liquid hydrogen fueling station installed by BMW at their facility in Oxnard, California. The 1,500-gallon liquid hydrogen tank is to the left of and behind the dispenser cabinet, which houses the hose, nozzle, and controls. The station design is conceptually simple in that the liquid hydrogen is pressure-transferred (typically at roughly 50 psig) from the storage tank to the vehicle tank and no pumps or compressors are needed.

Figure 2-14. BMW's station in Oxnard is a relatively simple and compact design for dispensing liquid hydrogen.

Figure 2-15 shows the Linde liquid hydrogen refueling coupling (also called a nozzle) that connects to the vehicle receptacle. It is a positive-locking dry-break type coupling with vacuum-jacketed concentric liquid and vapor flow passages. Liquid hydrogen flows in the center tube and cold vapor is returned through the surrounding annulus. When the coupling is connected to the vehicle receptacle, an automatic sequence starts which includes opening of valves in the coupling and receptacle, projection of the inner tube into the receptacle, helium gas purge, leak check, initiating liquid hydrogen flow while returning vapor during cool down, filling the vehicle tank with liquid hydrogen, and a pre-disconnect refueling termination sequence.

Figure 2-15. The Linde liquid hydrogen refueling coupling is used at the CaFCP West Sacramento and BMW Oxnard stations.

2.8 Station Type Suitability

Figure 2-16 shows the approximate ranges of daily hydrogen usage for which each of the previously discussed fueling stations are suited. These ranges are general approximations, and they will change as technology evolves and more hydrogen fueling station experience is gained. Station design suitability is also highly site and situation specific, e.g., it depends on proximity to central hydrogen plants, site conditions, and capital versus operating cost tradeoffs. Also, the hydrogen pipeline-supplied fueling station option shown in Figure 2-16 is a unique case because, as discussed in Section 2.3, there are very few hydrogen pipelines in California, and so this option is not generally available to station planners. After the best-suited hydrogen fueling station type is selected, the sizes of components such as compressors, compressed or liquid hydrogen storage vessels, and electrolyzers or reformers can be specified based on the required station dispensing capacity and frequency (i.e., numbers of vehicles, their estimated fuel consumption, and how evenly spaced refueling is during the day).

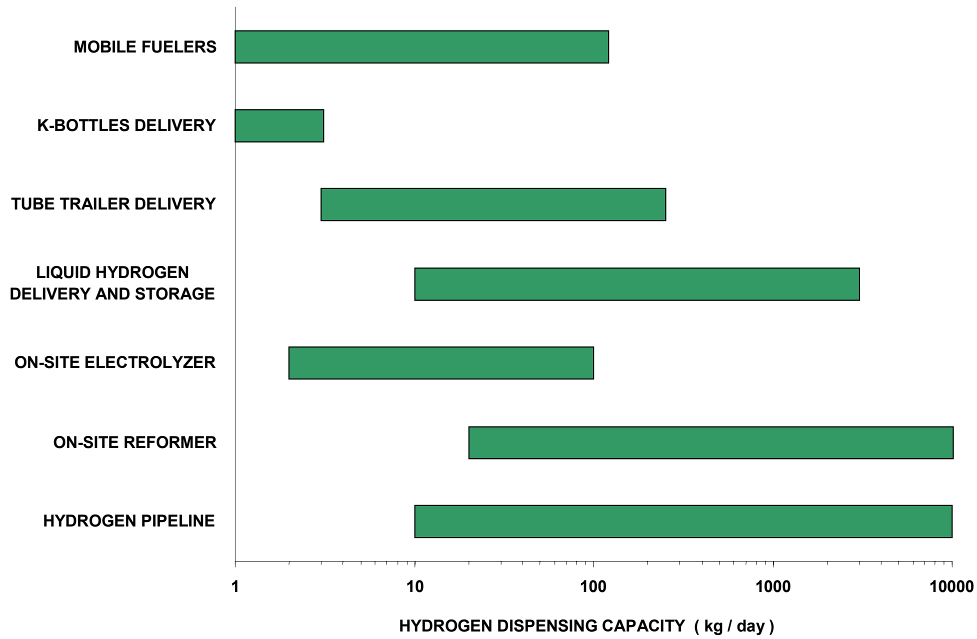


Figure 2-16. The ranges of hydrogen dispensing capacities appropriate to various types of fueling stations

3. Station Permitting, Contracting, and Installation

Hydrogen fueling stations in California are currently permitted through individual site-specific efforts at the local level. Some stakeholders are finding that this process is challenging due to a lack of State regulations that specifically apply to hydrogen fueling stations, which results in local jurisdictions having to make permitting decisions with guidance from related regulations, codes of practice, and standards for equipment. Section 3.1 summarizes the permitting process, potentially applicable codes and standards, and efforts to develop codes and standards specific to hydrogen fueling stations. Section 3.2 discusses issues associated with contracting for station design and installation.

3.1 Codes, Standards, Regulations, and Permitting

A site owner or contractor who wishes to install a hydrogen fueling station must make a case to the local permitting authorities that the planned station meets their safety requirements. One way to achieve this is by developing a building and equipment design that complies with well-known codes of practice, equipment standards, and government regulations. Although codes and standards are not necessarily regulatory requirements enforced by a state or federal agency, compliance with them is widely accepted as evidence of a safe design. Government agencies often do adopt these codes and standards in their own laws and regulations, meaning that codes and standards frequently overlap state regulations. In California, the design must comply with State regulations for safety but the State is not involved in permitting the fueling station project.

Some of the most widely accepted standards and codes of practice are National Fire Protection Association (NFPA) standards and the National Electric Code. The International Code Council (ICC) also develops documents much like the NFPA. The equipment standard references in these documents have several sources, such as the American Society of Mechanical Engineers (ASME). Documents from the Society of Automotive Engineers (SAE) and the US Department of Transportation (DOT) are also relevant, although these are generally more applicable to fuel delivery and on-vehicle hydrogen systems rather than the permanently installed fueling stations.

In conjunction with the local authority's approval of a design based on compliance with well-respected codes and standards, the design must meet the industrial safety sections of the State occupational safety and health regulations (Title 8, Chapter 4, of the California Code of Regulations). These regulations are established by a California State agency called Cal/OSHA. Although Cal/OSHA does not have the jurisdiction to permit a station, the station does need to comply with the regulations.

So far, neither the Cal/OSHA regulations nor most of the common codes and standards frequently cited in California specifically address hydrogen fueling stations. As a result, installation of existing stations has depended on references to related codes, standards, and regulations. Table 3-1 lists some example codes, standards, and regulations that

Table 3-1. Example codes, standards, and regulations potentially applicable to hydrogen fueling stations.

Organization	Code, Standard, or Regulation	Status/Reference
NFPA	50A — Gaseous Hydrogen Systems at Consumer Sites	NFPA is working to develop standards for hydrogen stations. NFPA 50A and 50B will be combined in NFPA 55.
NFPA	50B — Liquid Hydrogen Systems at Consumer Site	
NFPA	52 — CNG Vehicular fuel Systems	These NFPA CNG and LNG vehicle standards are related to hydrogen vehicles. NFPA is working to include hydrogen in these standards, which may be combined
NFPA	57 — LNG Vehicular Fuel Systems	
NFPA	30A — Motor Fuel Dispensing Facilities and Repair Garages	Current
NFPA	1 — Uniform Fire Code	Current
ASME	Boiler and Pressure Vessel Code, Section VIII	These are current codes. ASME has formed a Hydrogen Steering Committee to address hydrogen vehicle codes.
ASME	B31.3 — Process Piping	
CGA	G 5.4 — Standard for Hydrogen Piping at Consumer Locations	Current
CGA	G 5.5 — Hydrogen Vent Systems	Current
ICC	International Fuel Gas Code	HCSCC is working with ICC to address hydrogen vehicle requirements.
ICC	International Building Code	
SAE	J2600 — Recommended Practice for Hydrogen Refueling Connection Devices	Published
SAE	J2578 — General FCEV Safety	Published
SAE	J2579 — Hydrogen Vehicle Fuel Safety Systems	Being drafted (not yet balloted)
SAE	J2601 — Refueling Communication Device/Protocol	Being drafted (not yet balloted)
ANSI/AGA	NGV 1 — CNG Vehicle Fueling Connection devices	These current NGV standards are related to hydrogen vehicle applications
ANSI/AGA	NGV 2 — Basic Requirements for CNG Vehicle Fuel Containers	
ANSI/AGA	NGV 4.1 — NGV Dispensing Systems	
ANSI/AGA	NGV 4.4 — Breakaway Devices for Natural Gas Dispensing Hoses	
U.S. DOT	CFR Title 49, Parts 100-199, Transportation of Hazardous materials	Applies to hydrogen transportation
U.S. DOT	CFR Title 49, Part 571, Federal Motor Vehicle Safety Standards (FMVSS)	May need revision to include hydrogen
CHP	CCR, Title 13 (Motor Vehicles), Division 2 (CHP), Chapter 4 (special equipment)	Currently addresses CNG and LNG, being modified to include hydrogen
California OSHA	CCR, Title 8 (DOSH), various sections including Unfired Pressure Vessel Safety Orders	Many parts of current Title 8 apply to hydrogen fueling stations.

Acronyms:

NFPA — National Fire Protection Association
ASME — American Society of Mechanical Engineers
CGA — Compressed Gas Association
ICC — International Codes Council
SAE — Society of Automotive Engineers
ANSI — American National Standards Institute
AGA — American Gas Association
DOT — Department of Transportation
CFR — Code of Federal Regulations
CHP — California Highway Patrol
CCR — California Code of Regulations
OSHA — Occupational Safety and Health Agency
DOSH — Department of Occupational Safety and Health

are potentially applicable to hydrogen fueling station and may be cited in the permitting process. This table also lists some codes that are currently being developed.

Several groups in the United States and other countries are working to modify existing and draft new codes and standards to address hydrogen use as an automotive fuel. Many of these groups are cooperating in this effort. For example, under the U.S. Department of Energy (DOE) sponsorship, the National Renewable Energy Laboratory (NREL) and National Hydrogen Association (NHA) have organized the DOE Hydrogen Codes and Standards Coordinating Committee (HCSCC). The mission of the HCSCC is to coordinate the development and implementation of a consistent set of hydrogen-related codes and standards that will ensure the safe production, delivery, and use of hydrogen, and facilitate the accelerated commercialization of hydrogen technologies for stationary, transportation, and portable applications.

Many of the previously discussed organizations such as the NFPA, ICC, SAE, ASME, and others are supporting the HCSCC work. The HCSCC has periodic meetings to facilitate and coordinate the progress of hydrogen codes and standards development efforts. Separate from but in support of the HCSCC work, many organizations such as ASME, SAE, and NFPA have organized committees to develop hydrogen-related codes, standards, and recommended practices.

A currently important code-compliance issue in California pertains to the use of particular types of hydrogen storage tanks at refueling facilities. CCR Title 8 Section 460(b) requires that permanent storage tanks must be ASME stamped. DOT-stamped tanks may be used in transporting hydrogen to the facility or in fueling vehicle tanks directly, but they may not be installed on site. At this time, DOT-approved carbon fiber or fiberglass-reinforced tanks, also known as composite tanks, may not be used for permanent storage on-site because they are not covered by the ASME code. Cal/OSHA reports that ASME is currently developing guidance on composite material pressure vessels. The agency expects to make revisions to regulations as soon as ASME develops new code cases for stationary use of these tanks.

Hydrogen fueling station installations are normally subject to permit processes by city and/or county agencies such as planning, building, and fire departments. For unique or lesser-known automotive fuels, such as hydrogen, more comprehensive plan checks or other procedures can be expected. The site owner or contractor should be especially diligent in researching and investigating all parties who will determine the project’s permitting requirements. The organization, office, or individual responsible for approving the station is referred to as the Authority Having Jurisdiction (AHJ). Table 3-2 summarizes the basic steps commonly involved in the permitting process, although these steps can differ depending on local procedures and the AHJ.

Table 3-2. A typical initial checklist for beginning the permitting process for a hydrogen fueling station

Checklist
• Determine the role of local jurisdictions such as fire, planning, and building departments
• Contact appropriate agencies and/or the Authority Having Jurisdiction (AHJ)
• Initially describe the project and seek “gut level” concerns
• Identify and contact experts who can help address these concerns
• Refer AHJ to other AHJs who have approved similar projects in their jurisdictions
• Assess the need for community outreach or education programs
• Apply for needed building, fire, and other permits
• Pay all applicable construction, license, and other fees
• Maintain close contact with the AHJ while developing documents and during the review process

3.2 Contracting for Station Design and Installation

Contracting for hydrogen fueling station design and installation is often constrained by the fleet or site owner’s contracting procedures and/or restrictions associated with the source of the funds. Because hydrogen fueling stations are relatively unusual and permitting is not routine, these procedures and restrictions can be a challenge for efficient station installation contracting.

For example, transit agencies (which may need hydrogen fueling facilities for fuel cell buses) are often a form of local government or joint powers authority. As such, they usually follow public works contracting procedures, which require a two-phase process for facilities such as fueling stations: a request for qualifications (RFQ) for the design, followed by an invitation for bid (IFB) for the construction. Parties involved in the first phase are usually precluded from being equipment suppliers in the second phase. This can present a dilemma in the case of a hydrogen fueling station because firms with appropriate design capabilities (e.g., electrolyzer manufacturers, reformer manufacturers, industrial gas companies) may also wish to supply equipment and/or be involved in the construction. If these firms are not involved in the design phase, a less-than-optimum design can result, and this can produce problems ranging from costly redesign during the construction phase to disagreements regarding which firm is responsible for any subsequent station performance problems. Rigid application of separate design-build contracting can also present problems when designs are regarded as proprietary by participating firms.

These contracting procedures and restrictions have resulted in delays, increased costs, and alleged performance problems for prior CNG, LNG, and hydrogen fueling station installations. Experience indicates that success is enhanced when the public agency engineering staff and contracting department are able to cooperate and interpret contracting procedures to fit the unusual requirements of a hydrogen fueling facility. For example, the scope of the design phase can be defined to include the general architectural aspects of the project and the general performance specifications of the hydrogen fueling requirements. The installation contract can then include the technical design and equipment details of the hydrogen fueling system, in which case the installation contractor (which is usually a team consisting of a construction general contractor and the hydrogen equipment designer/supplier) is clearly responsible for the successful operation of this system.

Of course, private fleets or sites that install hydrogen fueling stations without government funding assistance are not constrained by public works contracting procedures. In this case, a combined design-build contract may be the best way to procure the hydrogen fueling station. Assuming that the station is procured through a competitive proposal process, the solicitation should contain at least a detailed specification package (including performance requirements, fleet characteristics, and site conditions), proposal content instructions, and evaluation criteria.